Coating Degradation of First and Second Stage Gas Turbine Blades

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(Received August 4, 2009)

ABSTRACT

Degradation study of over-aluminized CoCrAlY coatings (GT-29+) on conventionally cast (CC) GTD-111 Ni based super alloy substrates was investigated by evaluating first and second stage turbine blades after their 48,000 h of original services. The degradation evidences such as enlargement of the inter-diffusion zone, aluminum depletion from both top aluminide and CoCrAlY coating and related phase formations were observed by using an EPMA. The elemental mapping and quantitative analysis of the phases were also performed using WDS device attached to EPMA. Microhardness changes along the duplex coating thickness for both blades were determined by a Vickers microhardness tester.

Keywords: Turbine blade, coating, degradation, GTD-111, GT-29+

1. INTRODUCTION

Heavy-duty gas turbine technology is used for power generation either in simple cycle or in combined cycle with a steam turbine to obtain maximum efficiency. There has been great interest for these turbines in improving performance in output and heat rate, extension of inspection intervals as shortening their duration, emission reductions, life extension, etc /1-7/. Last two decades, a nickel based super alloy, GTD-111, has been used in GE MS9001 turbines as substrate materials of both first and second stage turbine blades providing the industry standard in corrosion resistance and a creep rupture/low-cycle fatigue advantage over the previously used IN-738 alloy /1.2/. Besides, CoCrAlY or NiCoCrAlY coatings with top aluminide layer (GT-29+ or GT-33+) are used for GTD-111 bucket's exterior surface and the internal cooling holes. Both coating materials are applied by vacuum plasma spray, PVD or more recently HVOF spray methods. Subsequently, top aluminide layer are deposited onto the coatings by using standard pack aluminizing processes, optionally above the pack (ATP) or CVD processes /3/. There exist some degradation and life-prediction investigation studies on GT29(+)/GTD-111 or GT-33(+) /GTD-111 turbine blades /3-7/. For example, Daleo *et al.* investigated the failure mechanism, life assessment and safe refurbishment of top aluminized CoCrAlY alloy/GTD-111 turbine blades /3,4/. Cheruvu *et al.* /6/ studied on service run GE 6001B and 9000FA turbine blades to identify the in-service degradation mechanism for the dublex coatings. They also conducted a cyclic oxidation test on top aluminized GT-29 or GT-33 coated GTD-111 substrate specimens. They compared their findings with COATLIFE software which was developed for

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predicting the remaining life of combustion turbine coatings in land-based gas turbines.

The objective of this study is to investigate and compare the coating degradation behaviors of service-run first and second stage turbine blades composed of over-aluminized CoCrAlY alloys (GT-29+) over GTD-111 substrates.

2. EXPERIMENTAL

In this study, first and second stage turbine blades were detached from the same GE MS9001E (9E) industrial gas turbine after completing their 48000 h of original services. Both turbine blade substrates were made of conventionally cast (CC) GTD-111 Ni base super alloys. CoCrAlY coatings on these substrates were applied by a vacuum plasma spray (VPS) method following a pack-aluminizing process to form a single phase β-CoAl (GT-29+). The nominal compositions of a GTD-111 nickel base super alloy, a GT-29 CoCrAlY and its aluminide top coat taken from literature are shown in Table 1 /2,4,6/.

Table 1

Compositions of the GTD-111 nickel base super alloy and GT-29 CoCrAlY coating

	Cr	Co	W	Mo	Ti	Al	Ta	Y	C	B	Ni
GTD-111 /2/	14.0	9.5	3.8	1.5	4.9	3.0	2.8		0.1	0.01	Bal.
GT-29 /4/	29.0	Bal				6.0		0.5			
Over-aluminide β-CoAl /6/	11.2	66.5				22.3					

The specimens from trailing edge sections of both blades were displaced at approximately 25% airfoil height by wire-erosion technique for the metallurgical investigation. The microstructural analysis of the specimens were performed by an electro-probe-micro-analyzer (EPMA- Cameca SX100) equipped with three wave dispersive spectrometers (WDS). WDS and backscattered electron imaging (BSE) techniques were used to examine the specimens' surface. A Vickers microhardness test was performed throughout the duplex coating thickness for both blades with an indenting load of 100 g.

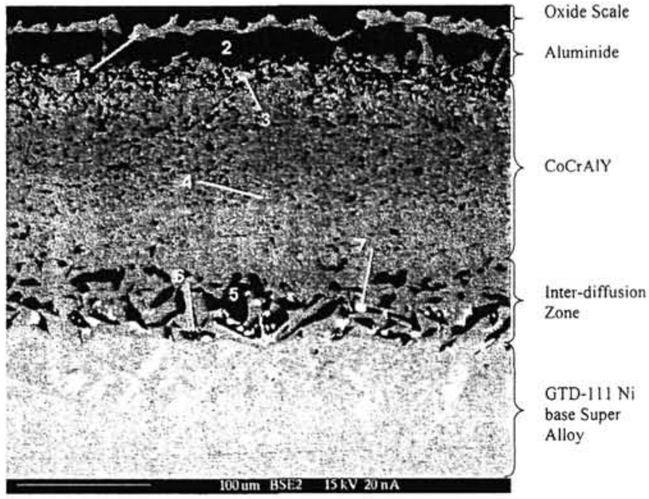

Fig. 1: The backscattered electron image (BSE) of the specimen displaced from the trailing section of first-stage-blade at 25% airfoil height.

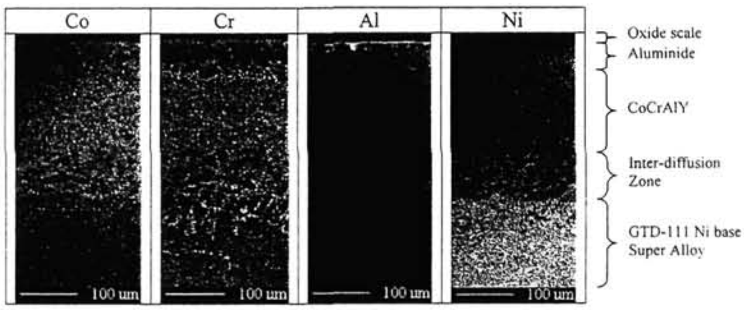

Fig. 2: EPMA XRD mapping for Co,Cr,Al,Ni of the specimen displaced from the trailing section of first-stage-blade at 25% airfoil height.

3. RESULTS AND DISCUSSION

The EPMA/BSE image of the specimen from the trailing edge section of the first stage blade shown in Figure 1 proved that the coating was severely degraded. Because of the up-diffusion from substrate region, nickel distributed all over the coating system. For example, top aluminide transformed from β-CoAl to β-(Co,Ni)Al matrix containing approximately 30 mass % Ni. Below the Al_2O_3 protective coating layer, some part of top aluminide transformed to γ-phase which is explained by Al diffusion to the surface in order to satisfy the need of Al_2O_3 reformation. σ(Co,Cr) formation was also observed just below the β(Co,Ni)Al aluminide layer. The enlargement of CoCrAlY/substrate alloy interface zone (~60 μm) was caused by the element diffusion occurred between the bond coat and the substrate. Primary MC carbide formations in (Ta_x,Ti_{1-x}) phases were observed where the growth zones of γ+β existed in the inter-diffusion layer. Most of β- phase precipitates in the CoCrAlY region dissolved due to inter-diffusion reactions in CoCrAlY/substrate alloy interface /2/. Quantitative analyses results of numbered locations in Figure 1 was identified by WDS and given in Table 2.

Table 2

EPMA-WDS measured phase compositions of specimen shown in Figure 1

No	mass %											Phase
	Ni	Co	Cr	Al	Y	Mo	Ta	Ti	C	O	W	
1	18 3	50.2	21.5	8.26	0.15	0.08		0.61				γ-Co rich
2	30.1	41.0	7.7	16.5								β-Co rich
3	4.93	41.6	49.9	0.59	0 63			2.13				σ-Cr rich
4	12.9	54.7	28.7	1.84	0.32	0.3		0.27				γ-Co rich
5	36.6	32.8	6.70	15.6				3.37				β-Ni rich
6				43.5						38.0		Al_2O_3
7		1.79	0.99			3 44	46.6	26.4	10.2		6.33	(Ta,Ti)C

The EPMA elemental mapping images of Co,Cr,Al and Ni in over aluminized first stage turbine blade coating is shown in Figure 2. As also mentioned above, Ni diffusion is clearly noticeable in both interdiffusion and top coat aluminide layer. The chromium rich layer below top aluminide bond coat corresponds to σ (Co,Cr) solid solution. Highest Al concentration detected on the surface represents Al_2O_3 protective layer. The dark area in CoCrAlY region of the Al mapping image proves the aluminum depletion.

The EPMA/BSE image of the specimen from trailing edge section of the second stage blade shown in Figure 3 proved that the degree of degradation of the coating was much less severe. Al_2O_3 dispersoids observed in the interface zone can be explained by the grit blast cleaning of GTD-111 substrate prior to VPS coating process /4/. The width of CoCrAlY/substrate

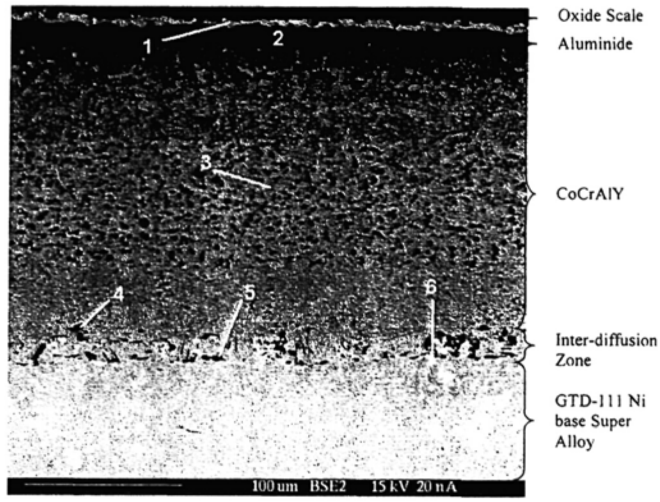

Fig. 3: The backscattered electron image (BSE) of the specimen displaced from the trailing section of second-stage-blade at 25% airfoil height.

alloy interface zone (~20 μm) and the grain sizes of γ, β, and (Ta,Ti)C phases which constituted the interface zone were found much smaller than that of first stage blade. CoCrAlY coating region still consisted of considerable amount of β- CoAl formations as small precipitates dispersed in γ-matrix. No σ (Co,Cr) formation was detected in the CoCrAlY coating region. The extent of nickel up-diffusion rate to the complete coating system was much less than that of first stage blade. For example top aluminide layer β-CoAl contains only 1 mass % Ni, whereas, γ-phase formation above top aluminide contains 1.44 mass % Ni. Quantitative analysis results of numbered locations in Figure 3 was identified by WDS and given in Table 3.

Table 3

EPMA-WDS measured phase compositions of specimen shown in Figure 3

No	mass %											Phase
	Ni	Co	Cr	Al	Y	Mo	Ta	Ti	C	O	W	
1	1.44	62 2	28 6	0.63				0 03				γ-Co rich
2	1.01	60.9	4 85	17.1	0.03							β-Co rich
3	6.19	56.7	26.2	2.99	0 29			0.30				σ-Co rich
4				57.9						29.1		Al_2O_3
5	35.4	32.9	5.75	14.3				2.62				β-Ni rich
6	0 75	1 51	0 83			2.61	47.6	23.5	15.2		7.23	(Ta,Ti)C

The Vickers hardness test is essential to evaluate the effect of microstructural changes on coating hardness. Figure 4 shows the Vickers hardness test results performed on top aluminide coated CoCrAlY/substrate specimens taken from both blades as a function of distance from coating surface. Horizontal bars shown in the figure represent the arithmetic mean length of two diagonals of the indentations left in the specimen's surfaces after removal of the 100 g load. The results show that the hardness values of both substrates change along the coating thickness. As can be expected, first stage turbine blade specimen has lower hardness values, since Al depletion resulted in a decrease in aluminide formation within duplex coating region. The hardest regions for both specimens were found where the small β- CoAl precipitations take place intensively at CoCrAlY region close to top aluminide single layer. However, high depletion of Al and formation of σ(Co,Cr) in the first stage blade specimen resulted in lower toughness values. After this region, the hardness value decreases with decreasing Al content along CoCrAlY coating. Lowest hardness values within both duplex coatings were found at the CoCrAlY region adjacent to inter-diffusion zone where the maximum Al depletion takes place. A small increase in hardness values was observed in the inter-diffusion zone due to the existence of β-(Co,Ni) rich grains having higher aluminum content and also MC formations.

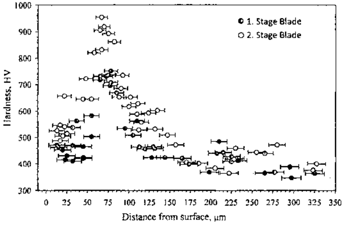

Fig. 4: Vickers hardness of first and second stage turbine blade specimens displaced from trailing section at 25% airfoil height.

4. CONCLUSION

It is concluded that the coating degradation of trailing edge section of first stage blade was found much severe than that of second stage blade, since it was exposed to higher temperature and pressure conditions. The degradation evidences are the enlargement the inter-diffusion zone, γ-phase formation between Al_2O_3 protective surface layer and β-top aluminide coating, and grain coarsening of γ and β in the inter-diffusion zone. Al depletion resulted in lower hardness values of the first stage turbine blade due to a decrease in aluminide formation.

ACKNOWLEDGEMENTS

The authors are pleased to acknowledge the support of the GE Energy Engineering Division and ITU Applied Research Center of Materials Science & Production Technologies.

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